SURVIVAL OF *QUERCUS DOUGLASII* (FAGACEAE) SEEDLINGS UNDER THE INFLUENCE OF FIRE AND GRAZING

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ABSTRACT

Recent burning and sheep grazing did not affect recruitment, survival, or growth of seedling *Quercus douglasii* Hooker & Arnott over four years at the Hopland Field Station, California. Recruitment did vary considerably among years. Once a seedling's shoot emerged, the probability of surviving to the next year remained constant, at about 0.5, unaffected by year, seedling size or age, past fire, or present sheep grazing. Established seedlings did not increase in size, and showed no indication of growing out of the seedling class into the sapling class. Successful natural regeneration appears to depend on factors controlling growth, not on factors associated with mortality during the seedling stage.

In many areas of California, *Quercus douglasii* (blue oak) regenerates poorly (Muick and Bartolome 1987). The age-structure of stands reveals abundant recruitment in the latter 19th and early 20th centuries (Griffin 1977) but little since. Often stands of a few large trees (diameter at breast height (dbh) >40 cm), many smaller trees (dbh >10 cm but <40 cm), and no saplings (dbh <10 cm), contain seedlings of less than 10 cm height (Muick and Bartolome 1987). A bottleneck in recruitment appears at the sapling stage because seedlings either do not establish or survive into the sapling class.

The causes for failure to recruit have been the subject of considerable speculation and include most environmental and managerial influences (Bartolome et al. 1987). Two factors of considerable importance, because they changed dramatically at the same time of the last period of significant blue oak recruitment, are livestock grazing and fire (McClaran and Bartolome 1989).

Experimental studies of the factors affecting seedling recruitment have used planted acorns (Griffin 1971; Adams et al. 1987; Borchert et al. 1989; Gordon et al. 1989; Matsuda et al. 1989). No study has combined naturally regenerating seedlings with an experimental treatment, although Swiecki et al. 1990 recently reported observations of marked naturally regenerating blue oaks at several northern California sites. Our experiment examines the effects of prescribed fire and sheep grazing on naturally regenerating blue oak seedlings.

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Methods

The study was conducted at the University of California's Hopland Field Station, located in Mendocino County, California. The 2168 ha station supports vegetation typical of the inner Coast Ranges: a mixture of open annual grasslands, oak woodlands of varying canopy coverage, and shrublands (Murphy and Heady 1983). Annual precipitation, concentrated in winter, averages about 95 cm, but during the four years of this study ranged from 60 to 72 cm. The two study pastures, each approximately 30 ha, have been grazed by sheep since before the establishment of the Station in 1951.

Vegetation in the experimental pastures is 76 percent blue oak woodland between 10 and 75 percent tree canopy cover and 18 percent open grassland with <10 percent overstory cover. The remaining 6 percent consists of dense oak stands with >75 percent canopy cover, usually with interior liveoaks (*Quercus wislizenii* A. de Candolle). The herbaceous understory is dominated by introduced annual grasses averaging 65 percent cover and 1500 kg ha^{-1} annual production (Bartolome 1986).

In fall 1986, three 0.5 ha experimental blocks were selected, having an overstory of blue oak (>10 cm dbh) and local canopy coverage of 50 percent. Each block had four treatments randomly applied to experimental units: 1) burning and sheep grazing, 2) burning and no sheep grazing, 3) no burning and sheep grazing, and 4) no burning and no sheep grazing.

Sheep, generally dry ewes, grazed the two study pastures each year from 15 May until 15 October, the dormant season in the annual grassland. Stocking rates were adjusted to produce residue levels in October close to the 600 kg ha^{-1} recommended for understory in mixed annual grassland and woodland (Clawson et al. 1982). On 15 October of each year the sheep were removed, to return 15 December. On 15 February animals were again removed until 15 May. Sheep grazed each pasture in the same seasons beginning in 1986. The grazing part of the experimental treatment compares sheep exclusion to the normal repeated seasonal grazing system in the pastures.

The prescribed burning was conducted in October 1986, after the first fall rains. Conditions were good for a fall burn, with temperatures at the time of the fire (1200 hr) 18°C and relative humidity at 40 percent. Wind speed was between 5 and 10 kph. Fuel consisted of a mix of dry grass, oak litter, and a small amount (50 kg ha^{-1}) of new grass totalling 750 kg ha^{-1}. Grass and oak litter at the soil surface were not completely consumed by the fire, but all herbaceous plants and all oak seedlings were top-killed.

We located two permanent 2 m × 10 m belt transects within each treatment combination (total n = 24) in which all blue oaks were

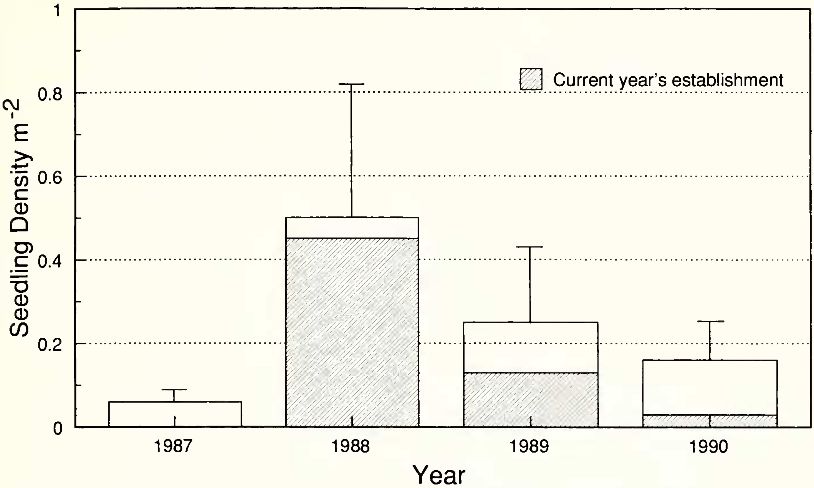

FIG. 1. Mean *Quercus douglasii* seedling densities by year on 24 2 × 10 m transects. Error bars represent 95% C.I. for means from t-values. Current year's establishment is not known for 1987.

counted yearly beginning in spring 1987. Beginning in May 1988 and continuing through May 1990 individuals were also permanently marked, mapped, and measured. Initially, only half of the individuals present were marked and mapped in 1988 on five of the transects; in 1989 and 1990 all individuals were marked and mapped. Measurements included number of seedlings, number of new seedlings, numbers and characteristics of seedlings surviving or dying. For each plant we measured height to top meristem, number of leaves, number of resprouts, and number of stems. Number of new seedlings was evaluated with analysis of variance using a randomized block split for time (Cook and Stubbendieck 1986). Other variables, which did not meet assumptions needed for analysis of variance, were analyzed by comparing means with t-tests or with simple regression.

RESULTS AND DISCUSSION

Average blue oak seedling density changed considerably among years on the experimental plots (Fig. 1). Seedling density was low in 1987, increased greatly in 1988, then declined towards 1987 levels in 1989 and 1990.

Dynamics within the seedling population are best examined by individually marking and following each new seedling as it appears and dies. Not surprisingly seedling appearance varied significantly by year from 1988 through 1990 (Table 1). Analysis of variance for

TABLE 1. RESULTS FOR ANALYSIS OF VARIANCE USING NEW BLUE OAK SEEDLINGS PER 40 M^2 AS DEPENDENT VARIABLE IN A RANDOMIZED BLOCK SPLIT FOR YEAR. Treatments: 1) grazed, burned; 2) ungrazed, burned; 3) grazed, unburned; and 4) ungrazed, unburned. Of the three possible F-ratios for this design, only the one marked * is significant for $F_{2,4}$ $P < 0.10$, others are not significant.

Source of variation	df	Sum of squares	MSE	F-ratio
Total	35	11,575	330.7	
Main plots	8	3292	411.5	
Blocks	2	638	319.0	
Year	2	1853	927.0	4.60*
Error	4	800.7	200.2	
Treatments	3	990.3	330.1	0.96
Year × treatments	6	1100.8	183.5	0.53
Subplots	18	6192	344.0	

new seedlings showed that only the year factor approached significance ($F = 4.60$, $P < 0.10$). However, even in the years of declining average density, 1989 and 1990 (Fig. 1), new seedlings continued to establish. Experimental treatments had no significant effect on number of new seedlings.

We were surprised to find that marked blue oak seedlings suffered similar mortality rates between years of about 50 percent (Table 2). Our results for mortality rates fall within the range of 5 to 65 percent per year found in the survey by Sweicki et al. (1990).

Plant size was unrelated to age (Table 3). Although the plants present in spring 1988, the oldest cohort followed, changed in size between years, averaging a taller stature in 1989, then shorter in 1990, this change is not related to age of the seedlings as the same pattern shows up each year for seedlings originating in the 1989 and 1990 cohorts. The 1990 season was simply poor for shoot growth in seedlings of all ages.

Mortality of seedlings was not significantly associated (t-test for mean differences between survivors and dead) with any measured characteristic of the plants the year prior to death, including age,

TABLE 2. TRANSITION PROBABILITIES AND SAMPLE SIZES FOR MARKED AND MAPPED *QUERCUS DOUGLASII* SEEDLINGS ON 24 2 × 20 M TRANSECTS. n = number of marked and mapped plants at beginning of period. P = proportion of plants alive and therefore surviving into the next sample period.

Years			
1988–1989		1989–1990	
n	P	n	P
110	0.51	56	0.57
		63	0.52

TABLE 3. NUMBER OF RESPROUTS, NUMBER OF LEAVES, AND HEIGHT OF *QUERCUS DOUGLASII* SEEDLINGS MEASURED EACH MAY. Numbers in parentheses are standard deviations. n is number of seedlings in each category. True seedling age is known for 1988 and 1989 cohorts, but not for the first year seedlings were marked, 1987 cohort.

Year	Age (yr)	Resprouts (no.)	Leaves (no.)	Height (cm)	n
Fall 1987 cohort					
1988	1+	1.74 (0.96)	5.99 (2.78)	4.33 (1.74)	110
1989	2+	2.84 (1.10)	5.66 (2.24)	5.08 (1.70)	56
1990	3+	2.94 (1.03)	5.09 (1.91)	3.73 (1.16)	32
Fall 1988 cohort					
1989	1	2.63 (0.91)	5.33 (2.71)	4.75 (1.93)	63
1990	2	2.76 (0.82)	4.51 (1.86)	3.65 (1.67)	33
Fall 1989 cohort					
1990	1	2.54 (0.65)	4.73 (1.76)	2.95 (1.18)	11

number of resprouts, or size of the seedling (Table 4). This result differs from the survey by Sweicki et al. (1990) who found a greater number of resprouts significantly associated with a higher likelihood of subsequent mortality. Our results have considerable importance for understanding natural regeneration and are contrary to the undocumented assumptions in the literature that blue oak seedlings are either ephemeral (Biswell 1956) or suffer increasing mortality as they age (White 1966).

These results have several important implications for understanding regeneration of blue oak. Seedling appearance varies considerably among years. Conditions in the fall of 1987 through spring 1988 were exceptionally good for seedling establishment, whereas the following years were not as good. However, even in the relatively poor years of 1989 and 1990 some new seedlings appeared.

Although often mentioned in the literature as factors influencing regeneration (Bartolome et al. 1987), sheep grazing and burning had no significant effect on seedling recruitment. Seedling establishment and initial survival did not differ due to burning or to sheep grazing. This result shows that seedling establishment is at least potentially compatible with fire and grazing. What it does not show is whether this result will hold for other sites. It also does not shed light on the role of fire and sheep browsing on the transition from seedling to sapling. Sapling blue oaks are not present in the study area and no

TABLE 4. NUMBER OF RESPROUTS, NUMBER OF LEAVES, AND HEIGHT OF *QUERCUS DOUGLASII* SEEDLINGS BY COHORT IN MAY OF YEAR PRIOR TO OBSERVED DEATH. Numbers in parentheses are standard deviations. n is number of seedlings in each category. True seedling age is known for 1988 and 1989 cohorts, but not for the first year seedlings were marked, 1987 cohort.

Year	Age (yr)	Resprouts (no.)	Leaves (no.)	Height (cm)	n
Fall 1987 cohort					
1988	1+	1.76 (1.00)	6.12 (3.43)	4.56 (2.03)	54
1989	2+	2.58 (0.74)	5.04 (2.67)	4.69 (2.03)	26
Fall 1988 cohort					
1989	1	2.59 (0.96)	5.00 (1.80)	5.09 (2.24)	29

seedling exceeded 12 cm height, thus the observations about seedlings do not suggest how sapling recruitment would be permitted.

The seedlings were present under a fairly dense canopy (50 percent) of blue oak. Most seedlings are found under and near the canopy (Muick and Bartolome 1987). Removal of the canopy may be needed for successful release but does not ensure release. The canopy may suppress seedling growth initially, then other factors may take over like browsing by wild and domestic animals, insect predation, fire, and competition with annuals. The constant mortality rate over time observed in this study suggests that none of these factors were important for seedling survival. This suggestion was also made recently by Sweicki et al. (1990).

Blue oak appears to possess a suitable strategy for the first stages of regeneration. Seedlings are always present in the understory, although numbers fluctuate, and spatial distribution is irregular. These seedlings suffered a constant mortality rate over time, awaiting conditions for release into the sapling stage. At Hopland those conditions did not appear on the study area.

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